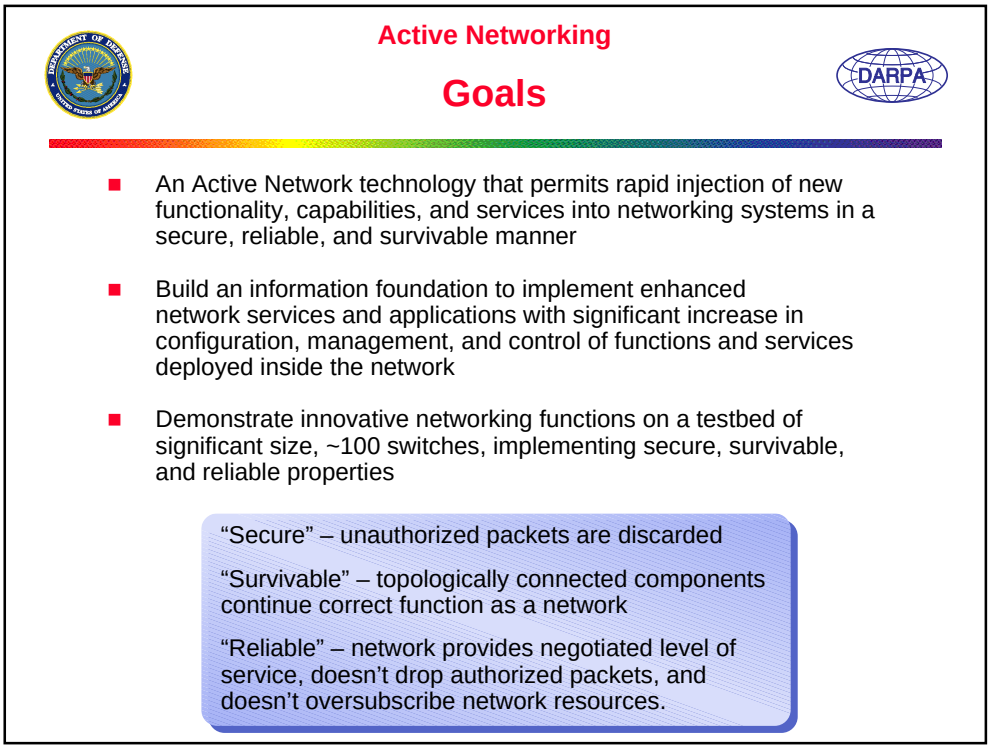

DARPA
Active Networking
Gary Minden

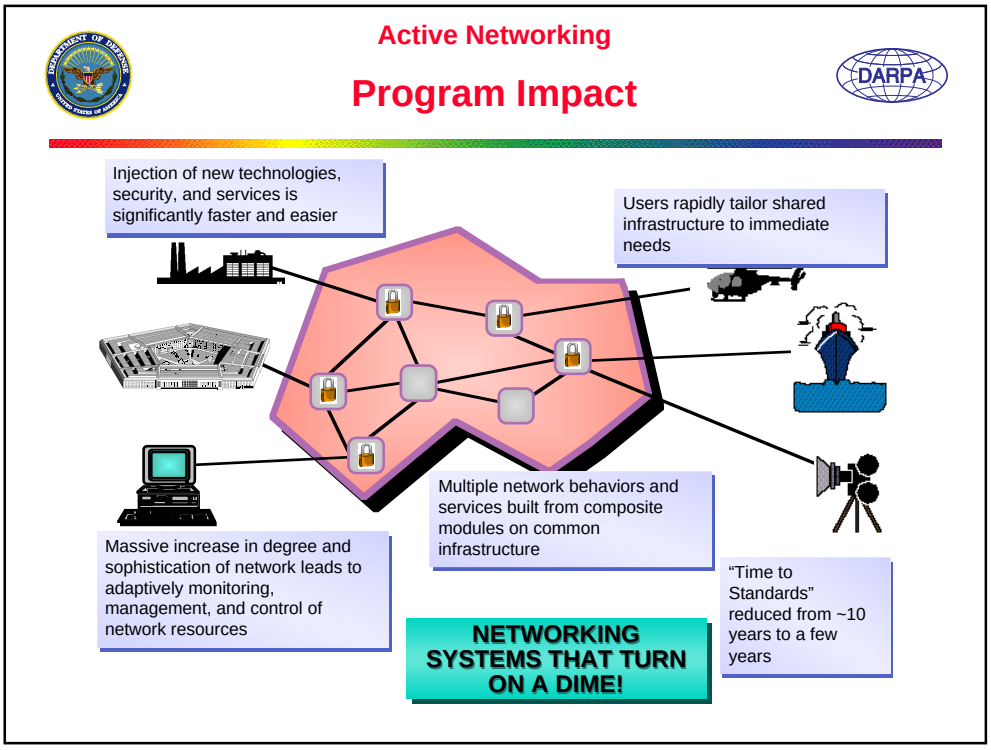


This program establishes three primary goals: an active network technology; an information foundation for Enhanced Network Services; and a demonstration of these innovative functions on a testbed of reasonable size.

The Active Network Technology enables networks to rapidly adapt to evolving requirements and challenges. The approach will allow user injection of "network-function elements" into a well-defined and protected, network-execution environment. While details of how this will be accomplished follow, it is important to state that network security and survivability properties are built into Active Networks from the beginning.

A second goal is to create a solid foundation for implementing Enhanced Network Services within the Active Network. Today's service model is "end-host-oriented". Services, such as WWW, Email and remote login, are implemented only on the edges of the network, but users seek additional services within the network for better performance. Services, such as multicast routing for multimedia and conferencing applications, caching services for quicker response, and location information to support mobile services, need to be implemented within the network. These services will be dynamic and require careful monitoring and management.

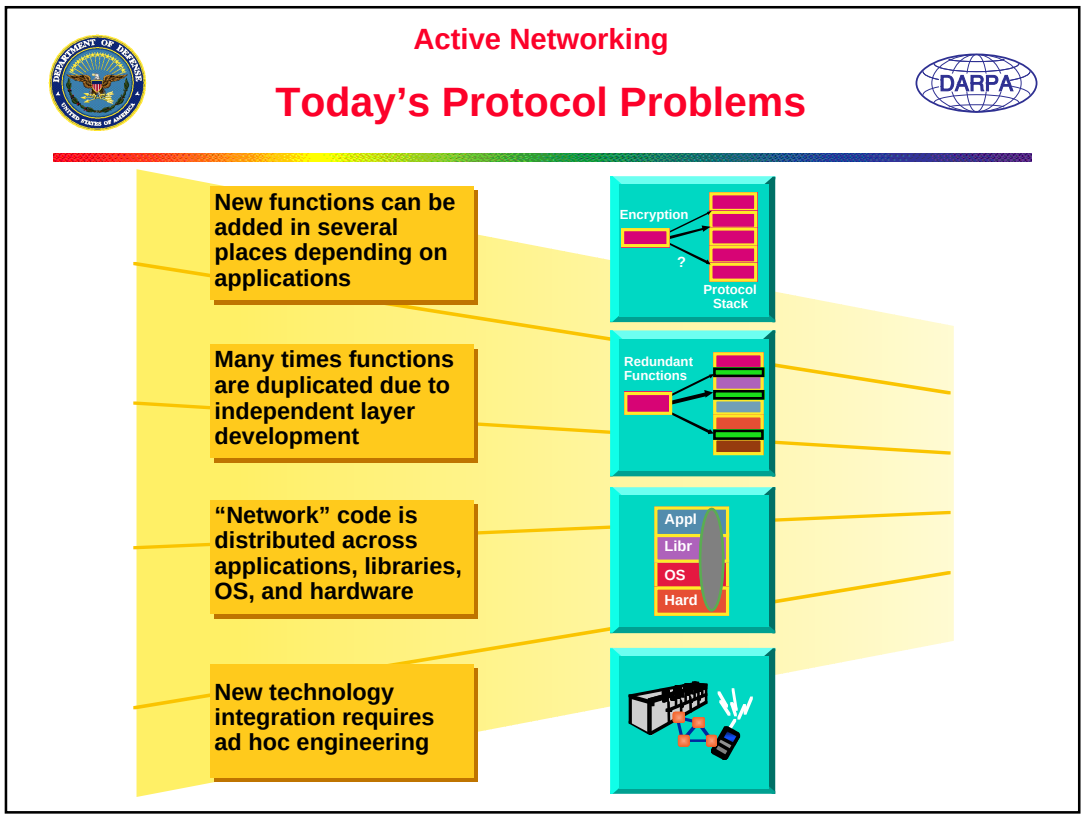
Finally, an important aspect is the deployment and evaluation of developed technology. Many issues arise and are addressed when systems are actually deployed. Central to this goal is the deployment on a substantial number of network switches and challenging the integrity of the system.



Active Networking will significantly change how new technology is brought into network capabilities. First, and foremost, users will tailor the network infrastructure to their immediate needs by injecting authorized "network function elements" via SmartPackets. The ability for users to inject their own network function elements means that timely requirements can be accommodated. It means new technologies can be incorporated into the network without having to reengineer or re-deploy the entire networking system. It means not having to wait, possibly several years, while the industry attempts to reach a consensus.

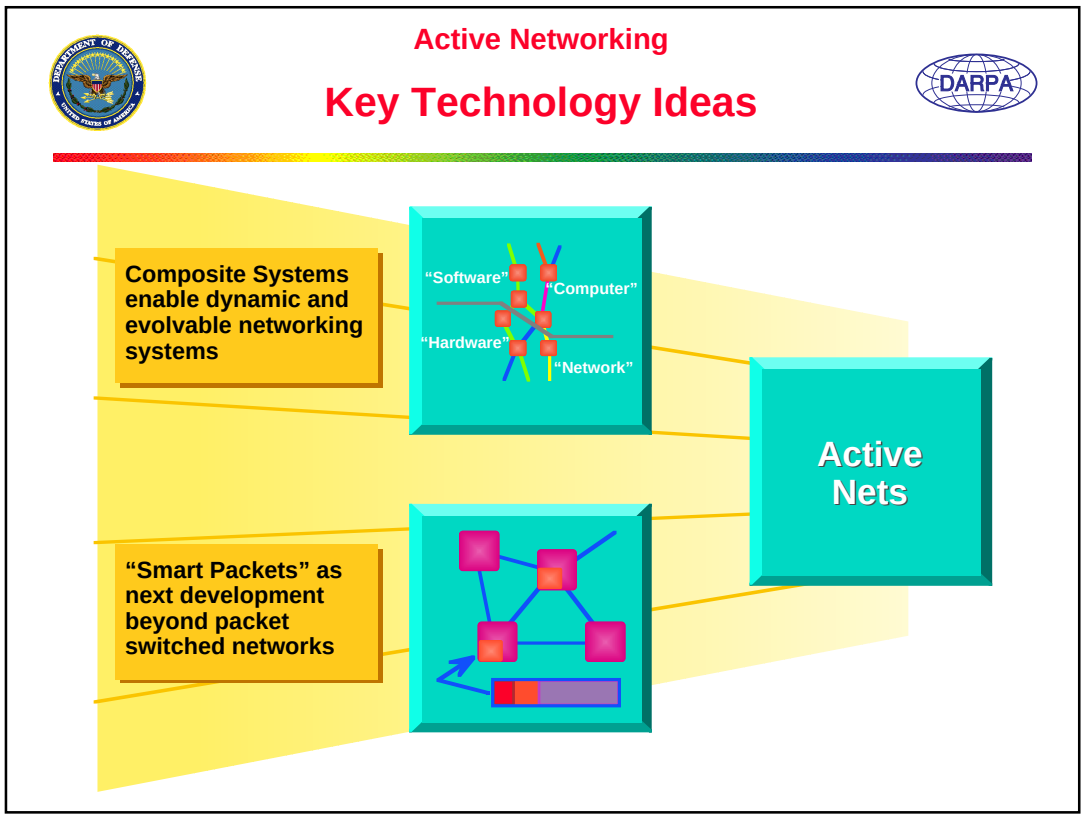
Active Networking requires a massive increase in the degree and sophistication of the network infrastructure. This, in turn, requires advanced techniques in the monitoring, management and control of network resources. These management techniques must be distributive, reliable and secure. Requirements for Active Networking will be achieved by creating secure and survivable Execution Environments and a strong foundation for Enhanced Networking Services.

The Active Networking structure allows for multiple implementations of Active Networking Execution Environments. As a result, environments can be tailored to the requirements at hand and/or changed should the networking structure appear to be compromised.



Today, four significant problems are recognized in the structure used to implement networking protocols:

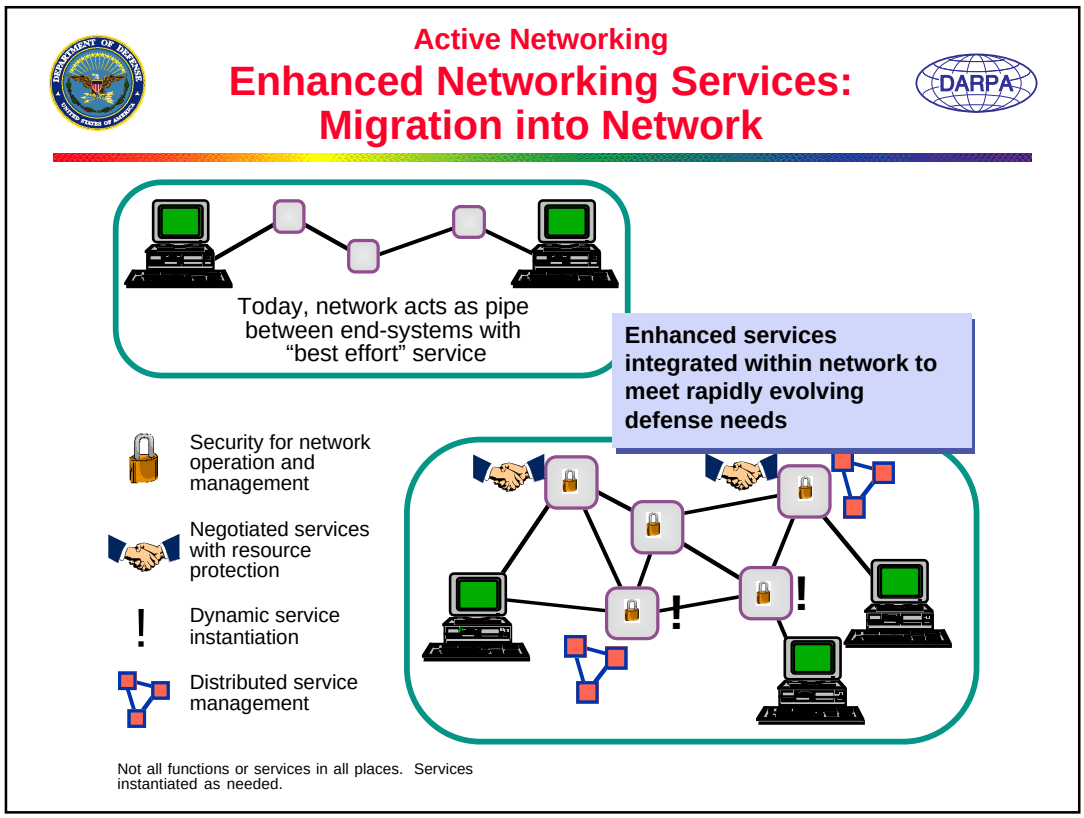
- First, the need to introduce new functions, such as encryption, into the protocol stack. However, the exact place to insert the encryption function depends on application requirements. In some cases it might only be necessary to encrypt application data. In other cases it might be necessary to mask all application traffic behind a traffic-masking function.
- Second, independently developed layers in protocol stacks often result in duplicate functions. Eliminating duplication will improve performance, reduce interactions, and reduce complexity.
- Third, conventional implementations of network protocols often show low performance. Many implementations attempt to circumvent the lack of performance by distributing network code through hardware, operating systems, runtime libraries, and applications. Thus, conventional implementations' lack of performance leads to disorganized and loosely controlled implementation of network protocols.
- Fourth, it is difficult to integrate new technologies, such as mobile, end-user systems, into pre-existing networking structures once they become available. Sometimes, integration can be accomplished by expensive, ad hoc engineering. Other times, attempts at integration fail and beneficial new technologies remain unutilized.



Active Networking introduces two key technology ideas:

- Networking systems and services can be built up from small modules with specific properties. These modules can be distributed as needed between hardware implementation or software implementation or between the "computer" or the "network". By making the distinction as fuzzy as possible network functions are allowed to migrate between software and hardware and the distinction between "computer" and "network" is blurred.
- Second, we introduce the idea of a SmartPacket. SmartPackets will be explained in detail later, but the key idea is that they carry address, procedure, and data within the packet.

The combination of composition and SmartPackets lead to Active Networking Technology.



Today's view of the network is one that the network carries bits from one end-user system to another, i.e., a pipeline. New requirements on the network, such as multicast, security, and management, are leading to the introduction of enhanced services into the network structure.

In the Enhanced Networking Services part of the program the issues of secure network operation and management, structures to negotiate network services and resources, techniques to instantiate new services entities within the network, and the management and control of these capabilities will be addressed.

Following these key technology ideas, services offered today by end systems could migrate into network structures.

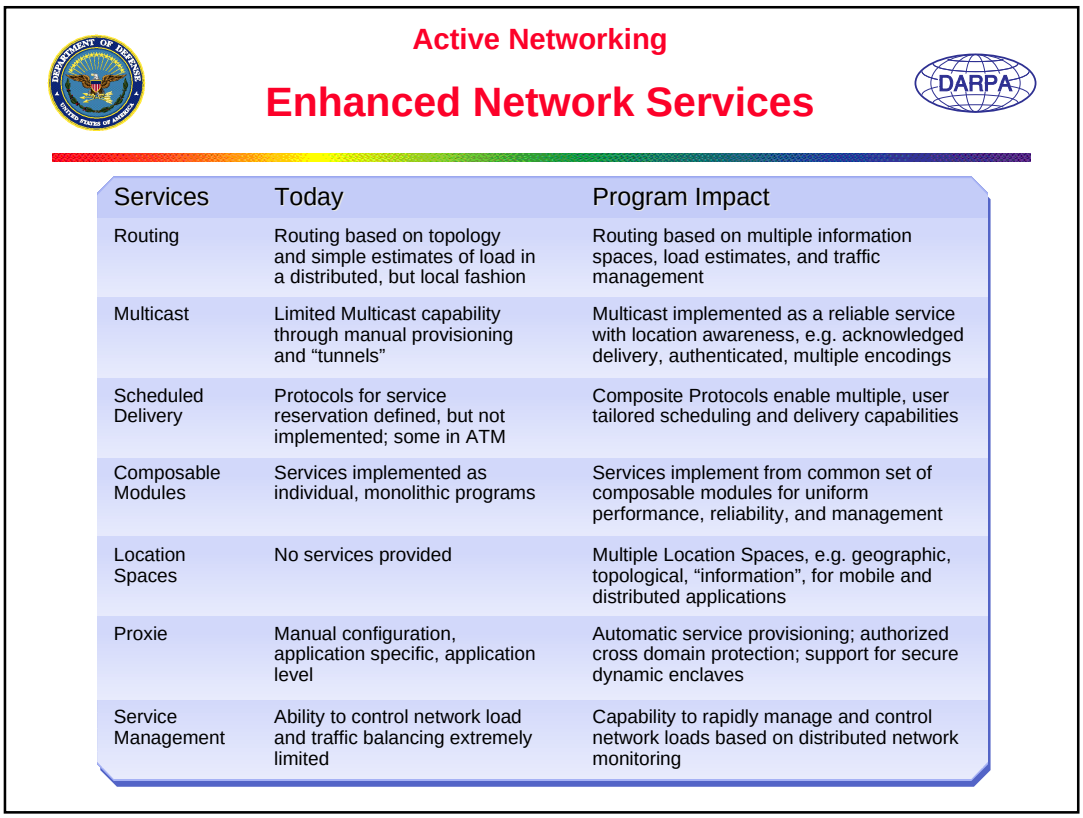
Active Networking

Enhanced Networking Services: Simple Analogy

What is a "Service"?	Telephone
Communication Capability	Voice Circuit, 3 kHz bandwidth
Tailored to user's requirements	Phone company offers residential, business, emergency, and high reliability services on same infrastructure
Negotiated performance • Throughput, delay, synchronization, routing, multicast, reliability	Customers contract with phone company for specific level of service, e.g. 1-800 call delivery
Managed, monitored, and controlled	Service provider provisions sufficient network resources, monitors and controls those resources to meet negotiated agreements
Architecture for growth and improvement	Phone company monitors population growth areas, new technologies, and invests capital when necessary to meet obligations

It is important to understand the meaning of "service". Within the networking program, "service" means: 1) communication; 2) meeting user requirements; 3) negotiation with the user; 4) monitoring and controlling; and 5) room for architecture to grow.

Network Services are analogous to the telephone services provided by common carriers.



Services	Today	Program Impact
Routing	Routing based on topology and simple estimates of load in a distributed, but local fashion	Routing based on multiple information spaces, load estimates, and traffic management
Multicast	Limited Multicast capability through manual provisioning and “tunnels”	Multicast implemented as a reliable service with location awareness, e.g. acknowledged delivery, authenticated, multiple encodings
Scheduled Delivery	Protocols for service reservation defined, but not implemented; some in ATM	Composite Protocols enable multiple, user tailored scheduling and delivery capabilities
Composable Modules	Services implemented as individual, monolithic programs	Services implement from common set of composable modules for uniform performance, reliability, and management
Location Spaces	No services provided	Multiple Location Spaces, e.g. geographic, topological, “information”, for mobile and distributed applications
Proxie	Manual configuration, application specific, application level	Automatic service provisioning; authorized cross domain protection; support for secure dynamic enclaves
Service Management	Ability to control network load and traffic balancing extremely limited	Capability to rapidly manage and control network loads based on distributed network monitoring

The areas to be addressed by Enhanced Networking Services are listed above. Many are derived from efforts initiated within the Networking Systems Program over the past several years.

New approaches address the ability to compose new services from a limited, well-defined set of modules, the need to address mobility and information space issues, the need to provide necessary services while protecting an entity’s resources, and the need to manage the new capabilities.

Technologies recently started in routing, multicast, and scheduled delivery need further investment and incorporation into the Enhanced Network Services foundation.

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Enhanced Networking Services: Technology Areas & Concentration

Negotiated Services

- Build enhanced services, e.g. routing on bifurcated networks, reliable multicast, synchronous delivery of objects and streams, self-configuring and dynamic networks, traffic management, and “Network Service Dispatcher”
- Create representations, specifications, and mechanisms to negotiate and control services for management and application use
- Create distributed management tools that cross multiple organization and vendor networks to meet agreed service levels and insure interoperability

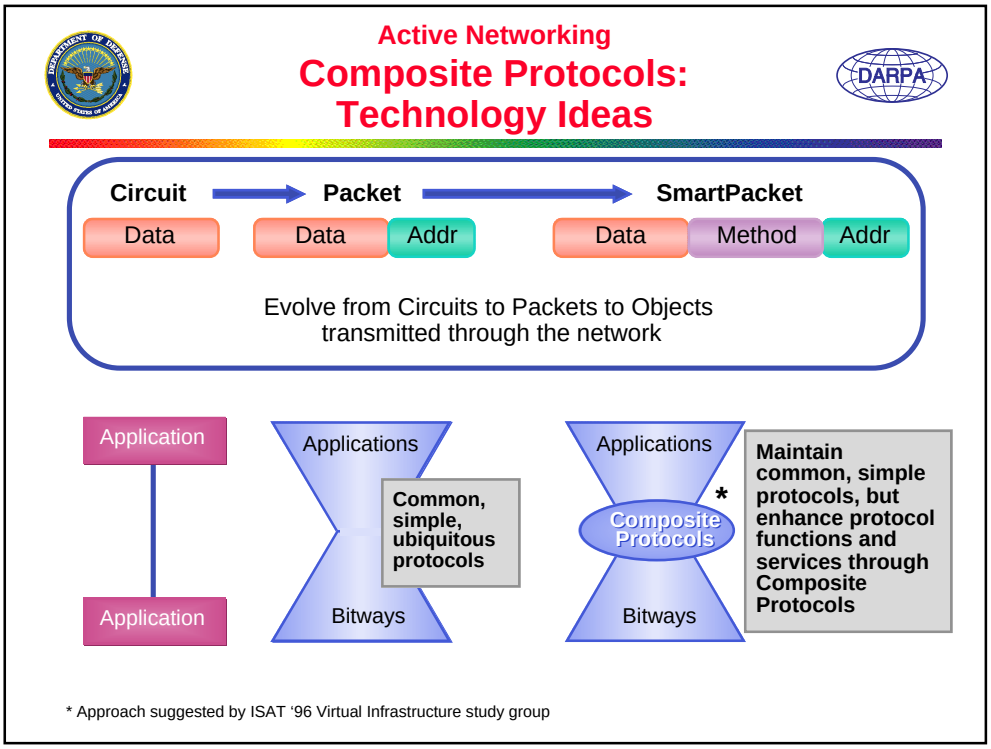
Location Aware Services

- Design, create, and implement multiple location spaces, e.g. physical, topological, and “Information Space”, that are critical to mobile and distributed applications and managing network load and architecture

Service Management and Proxies

- Define and create mechanisms to identify when to instantiate, where to locate, how to monitor and manage, and when to terminate enhanced services
- Create secure technology to enable authorized services to cross network protection mechanisms, e.g. firewalls

Here investments into Enhanced Networking Services technology and concentrations are further detailed.



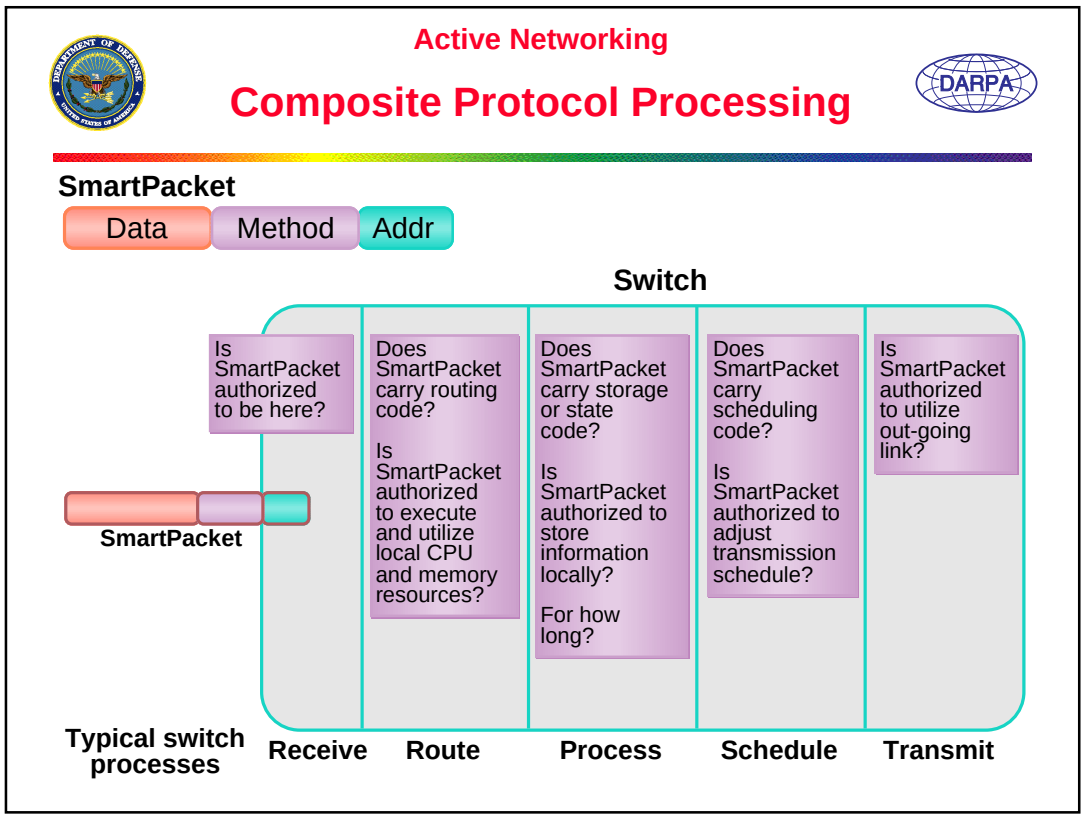
Composite Protocols are the next step beyond conventional packet technology and Open Data Networks.

The SmartPacket can be viewed as a natural step from circuit-based networks, through packet-switched networks to Active Networks.

While early circuit networks only require the end systems to agree to a protocol, interoperability between multiple types of end systems may be a problem.

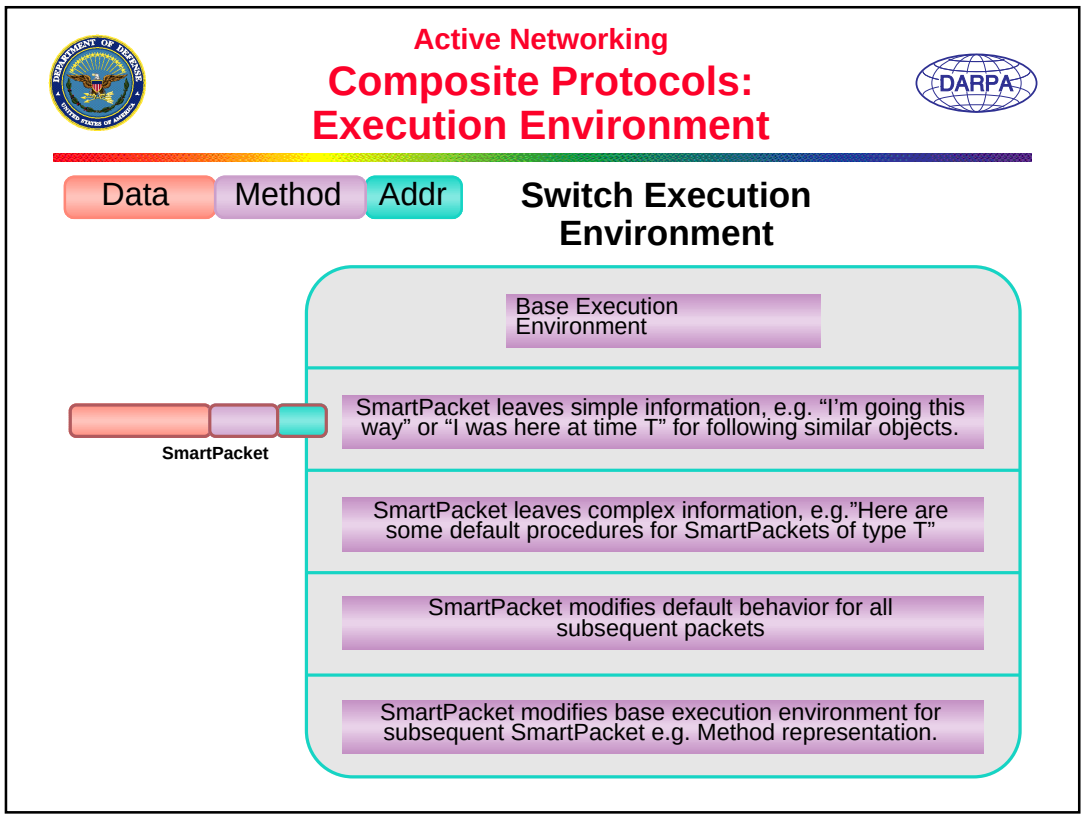
Packet networks eliminate many of the interoperability problems by using a common, simple, ubiquitous protocol, but they can constrain network services due to their need for wide distribution and simple implementation.

Composite Protocols maintains common, simple protocols but also enables extensible protocol functions and "network-functional elements" to be inserted into the network structure.



Composite Protocols is a flexible and diverse technology that will develop as the program advances. Initial concepts include the following steps described below. The checking of SmartPacket authorization for all resource utilization at each step through the switch is the most important concept. These checks protect the integrity of the network.

- Receive Process — Should the packet be here at all? The packet authorization should be checked very quickly and if authorized, allowed through; otherwise, discarded. Methods of "pushing bad packet sources" back through the network require investigation and development.
- Routing — If the SmartPacket carries routing code, and is authorized to execute, do so while determining the schedule and output port.
- Process — Some SmartPackets may leave "bread crumbs" behind for following SmartPackets. SmartPackets must be authorized to leave these "bread crumbs" and the trail must eventually expire so as to protect resources.
- Schedule — SmartPackets may schedule their transmission to achieve negotiated service guarantees.
- Transmission — Is the SmartPacket authorized to utilize the outgoing link?



Multiple, dynamic switch execution environments are envisioned. These environments are a difficult problem requiring detailed research and development.

- A base execution environment:
  - SmartPackets, if authorized, may leave simple information behind for following packets, e.g., “bread crumbs”
  - SmartPackets, if authorized, may leave procedures for following SmartPackets of Type “T”
  - SmartPackets, if authorized, may leave procedures for all following SmartPackets.
  - Finally, SmartPackets may modify the entire Switch Execution Environment.

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Composite Protocols: Hard Problems

Method Language

- Should multiple method languages be supported?
- How should security, survivability, reliability, and performance requirements be achieved?
- What levels of security, survivability, reliability, and performance are required?

Execution Environment

- What are efficient models of processors, memory, bitways, etc?
- What network switching resources must be modeled? e.g. routing tables, queues, schedules, etc.
- What are efficient and extensible implementations of class and object hierarchies?
- How to allocate and manage multiple resources, e.g. CPU, bandwidth, and memory, to insure reliable operation?
- Which formal properties, e.g. liveness, fairness, no data loss, should be specified and how to prove such properties?

There are many hard problems in developing Active Networking technology and implementing that technology in real networks. These initial challenges are identified in this slide. All challenges have reasonable solutions requiring exploration and research within the program.

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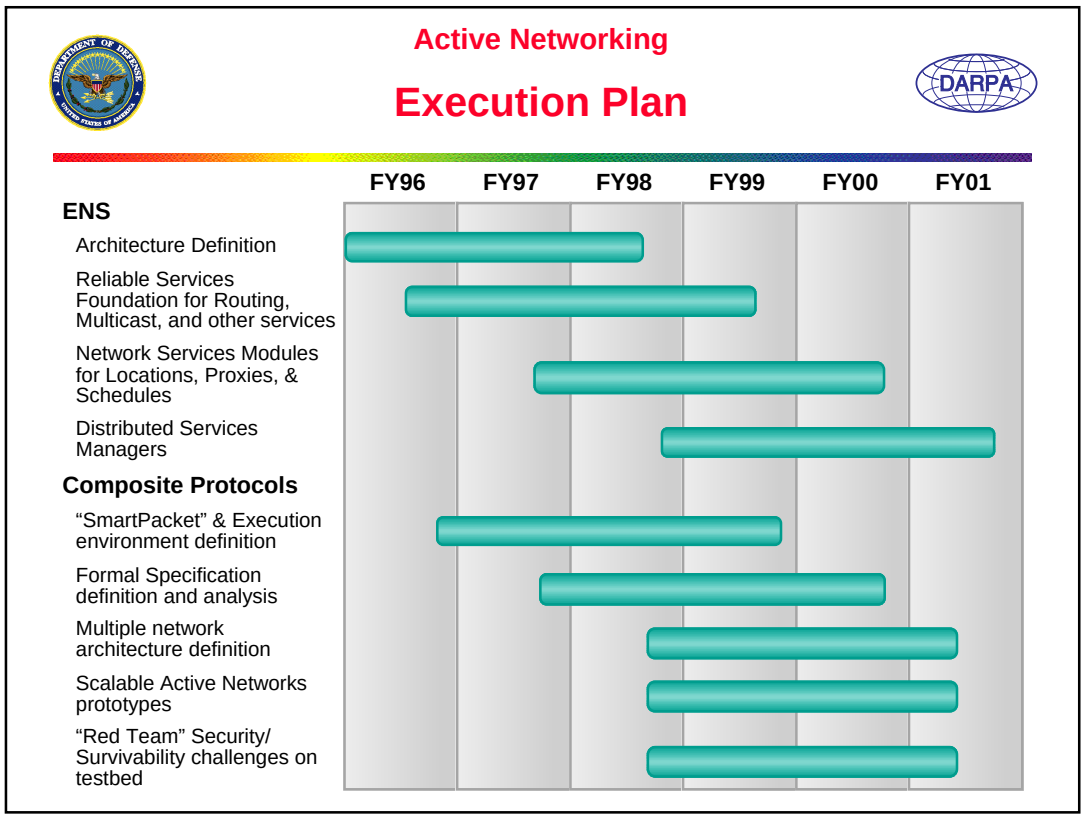
Composite Protocols: Hard Problems (cont.)

Fast Certification and Authorization

- What security policies should be implemented at the switches?
- How much processing resource should be allocated to certification and authorization?
- What techniques should be used for certification and authorization?

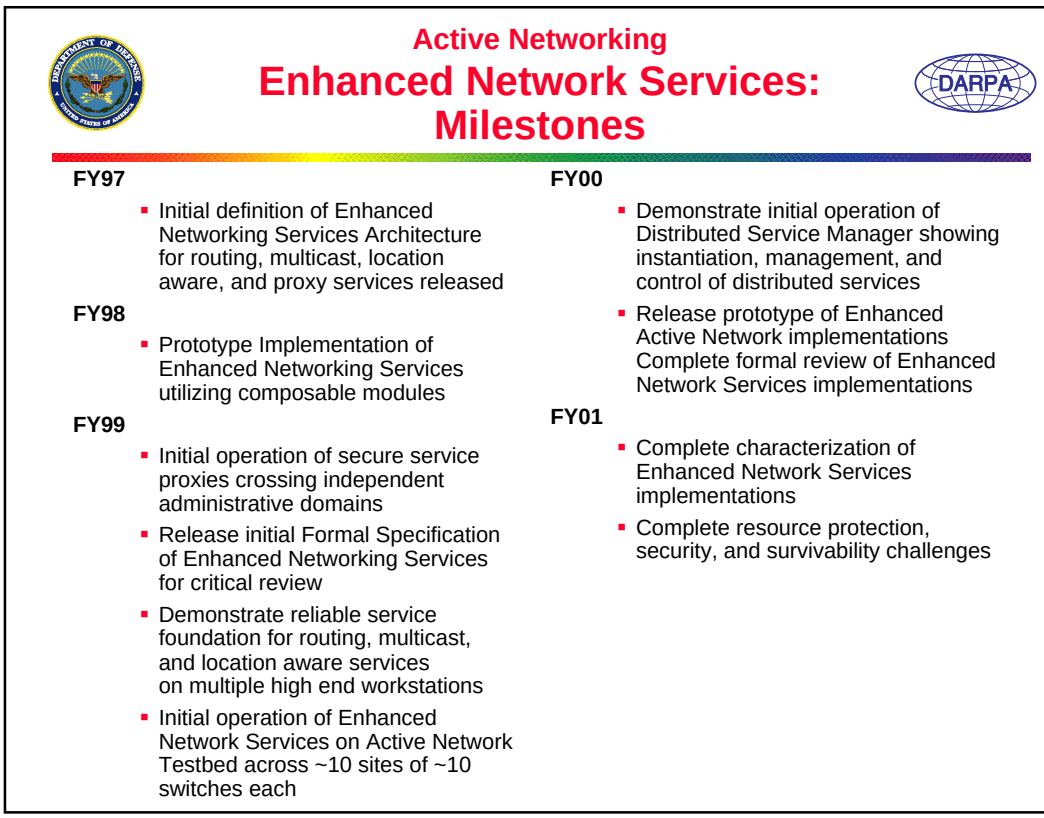
Management and Resource Allocation

- How to insure continued operation of network without resource exhaustion or logical deadlock?
- How to manage low level resources as memory, CPU time, and transmission capacity for services delivered?
- What level of control should be exercised?

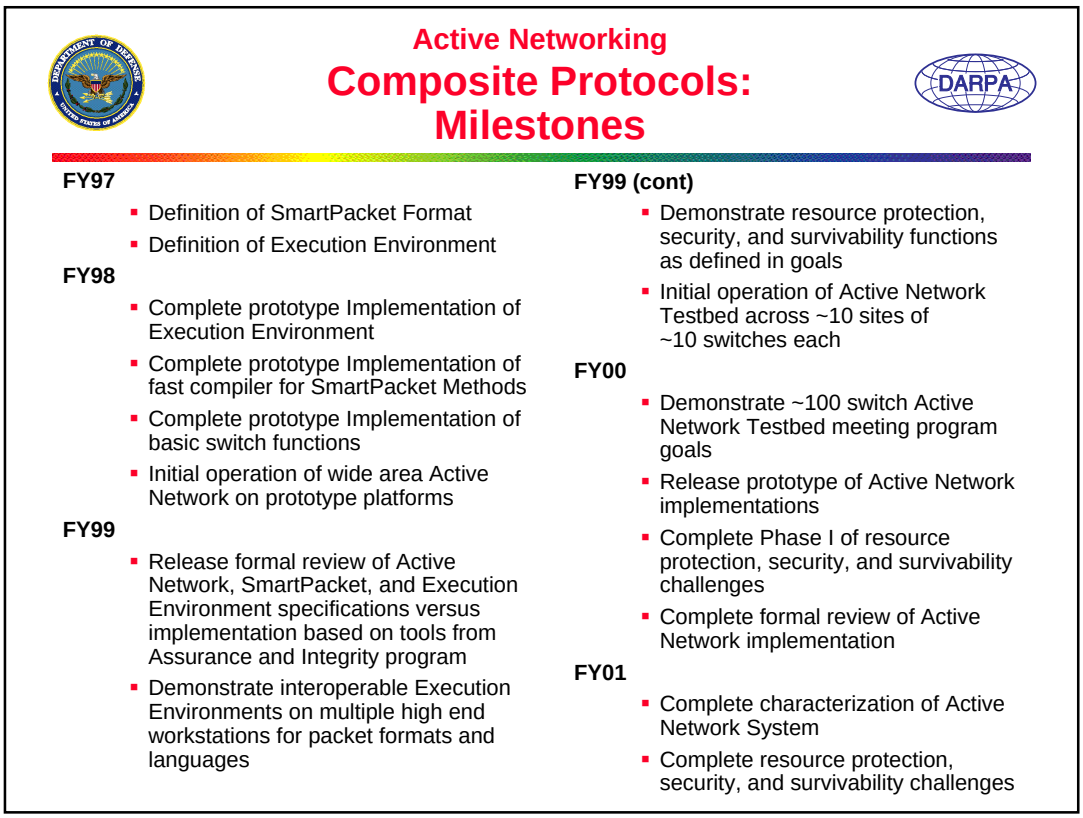


The execution plan outlines the key activities within the program.

- Enhanced Networking Services
  - Activities defining the network service architecture were initiated within the Network Systems Program
  - Research for routing, multicast, and Reservation Protocols will continue from FY96 through FY99
  - New service foundations and modules will start in FY97
  - Distributed management of implemented service will commence in FY98
- Composite Protocols
  - SmartPacket structure and execution environment definitions will commence in FY96
  - In FY97 formal specifications of the packets, protocols, and execution environments will be initiated
  - In FY 98, after significant development of the underlying technology, multiple Active Network architectures, test scalability, and test security and survivability properties will be expanded and tested



Program milestones in the Enhanced Network Services.



Program milestones in the Composite Protocols.

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Why Now?

- CPU technology is sufficiently advanced to consider implementing necessary processing of Active Networking technology based on SmartPackets
- Formal Methods are available to show specific, important security and survivability properties through logical reasoning process
- Object oriented design and implementations are available
- Experience of existing large scale network services and applications provides requirements for future networking services

The time is right!